ehp Environmental Health PERSPECTIVES
ehponline.org
Published by the National Institute of Environmental Health Sciences

# The Influence of Large Scale Airborne Particle Decline and Traffic Related Exposure on Children's Lung Function

**Dorothea Sugiri, Ulrich Ranft, Tamara Schikowski, and Ursula Krämer**

**doi:10.1289/ehp.8180 (available at http://dx.doi.org/)**
**Online 20 September 2005**

**The National Institute of Environmental Health Sciences**
**National Institutes of Health**
**U.S. Department of Health and Human Services**

Title: The Influence of Large Scale Airborne Particle Decline and Traffic Related Exposure on Children's Lung Function

Authors: Dorothea Sugiri[1], Ulrich Ranft[1], Tamara Schikowski[1], Ursula Krämer[1]

Author's affiliations:

[1]Institut für umweltmedizinische Forschung an der Heinrich-Heine-Universität Düsseldorf

Auf'm Hennekamp 50, D-40225 Düsseldorf.

Name and address of corresponding author:

Dorothea Sugiri

Institut für umweltmedizinische Forschung an der Heinrich-Heine-Universität Düsseldorf

Fon: +49 211-3389 299, Fax: +49 211-3389 283, E-Mail: sugiri@uni-duesseldorf.de

Acknowledgements:

The authors thank Dr. Mohamed S. Islam and his team for their excellent bodyplethymographic measurements: Erika Müller, Stanislav Wolczyk, Veronika Jaeger and Gabriele Seitner-Sorge.

The authors thank the local Health Departments in Borken, Cologne, Duisburg, Essen, Halle, Leipzig, Magdeburg, Osterburg and Salzwedel for their assistance and permission to couple our investigations to the official school entrance examinations. Our thanks also to Dr Heidemarie Willer and Dr Hanna Oppermann, who enabled the field work in East Germany and Dr Reinhard Dolgner who organized the study in West Germany. We also thank J. Edmonds, Environmental Health Officer in Stonnington, Victoria, Australia, and English native speaker for proofreading the manuscript.

The study was partly financed by the Ministry of the Environment of North-Rhine Westphalia and the Ministry of Social Affairs in Sachsen-Anhalt.

The authors declare they have no competing financial interests.

Short running head: particles and traffic influence lung function

Key words: air pollution, particulate matter, traffic, lung function, repeated cross sections, children, German reunification

Abbreviations

CI: confidence interval, FVC: forced expiratory capacity, $FEV_1$: forced expiratory volume in 1 second, MR: geometric means ratio, PEF: peak expiratory flow, PM: particulate matter, $PM_{10}$: particles with aerodynamic diameter less than 10 µm, r: coefficient of correlation, $R_{aw}$: airway resistance, TLC total lung capacity, TSP total suspended particles article descriptor: Children’s Health

Outline of manuscript section headers:

Abstract

Introduction

Materials and Methods

Results

Discussion

Conclusions

References

Tables

Figure Legends

Figures

Abstract

Between 1991 and 2000, ambient air pollution in East Germany has changed to West German quality: concentration of total suspended particles (TSP) decreased on a broad scale while traffic increased. During that time we analyzed total lung capacity (TLC) and airway resistance ($R_{aw}$) of East and West German children.

Children aged 5-7 years (N=2574) were tested with cooperation independent bodyplethysmography in repeated cross sections. Random effect models were used to determine the mutually adjusted association between lung function and short-term and chronic particle exposure and it's interaction with living near a busy road.

Annual averages of TSP declined from 77 $\mu g/m^3$ to 44 $\mu g/m^3$, averages on the day of investigation from 133 $\mu g/m^3$ to 30 $\mu g/m^3$. Differences in lung function between East and West German children vanished during the investigation time. The association of TSP with $R_{aw}$ and TLC was stronger in children living more than 50 m away from busy roads. East German children from this group had a $R_{aw}$ which was 2.5% higher (95% Confidence interval (CI) 0.0 – 5.1%) per 40 $\mu g/m^3$ increase of daily TSP averages. TLC decreased by 6.2% (CI: 0.04 – 11.6%) per 40 $\mu g/m^3$ increase in annual mean TSP and this effect was equally pronounced in East and West Germany.

TSP exposure decreased on a broad scale between 1991 and 2000. Lower concentrations of TSP were associated with better measures of lung function in six year old children. For children living near busy roads this effect was diminished.

## Introduction

Before the reunification of Germany in 1989, outdoor mass concentration of total suspended particles (TSP) was higher in East Germany than in West Germany due to emissions from industry and domestic sources. Traffic related air pollution was higher in West Germany,in comparison to East Germany. During the first years after reunification, TSP levels considerably declined in East Germany and reached the West German levels, but emissions from traffic increased. The size distribution of airborne particles exhibited a shift towards finer particles (Ebelt et al. 2001; Kreyling et al. 2003). The effect of this changing pattern on lung function in six year old children has not been investigated so far.

To date, evidence for an effect of ambient air pollution exposure on lung-function in children comes from studies investigating school children at least eight years old. All these studies used spirometric measures (forced expiratory capacity (FVC), forced expiratory volume in 1 second ($FEV_1$) and peak expiratory flow (PEF)) which depends on cooperation of the children and thus is more difficult to manage in children of a younger age. Most studies with one exception (Dockery et al. 1989) found an adverse association with chronic exposure to air pollution (Islam and Schlipköter 1993; Peters et al. 1999; Pope and Arden 2000; Schindl 1993; Schwartz 1989). Elevated levels of urban ambient air pollution were found to retard development of children's lung function (He et al.1993, Gauderman et al. 2000,Gauderman et al. 2002, Gauderman et al. 2004). Decline of long-term exposure to air pollution was associated with an increase of forced expiratory vital capacity (Frye et al. 2003). Lung function of children has been associated with traffic related exposure in a number of epidemiological studies (Brunekreef et al. 1997; Fritz and Herbarth 2001; Wjst et al 1993). Acute effects were mostly investigated independently from long-term effects. Short-term ambient exposure of children to fine particles (Hoek et al. 1998) or winter air pollution (Peakcock et al. 2003) resulted in peak expiratory flow decrement and small, but statistically significant decline in forced expiratory volumes in 0.75 and 1 second (Pope and Arden 2000). Adults also showed decreased forced expiratory volumes and flows (Schindler et al 2001).

In this study we add following new aspects to the already known body of evidence concerning the association between outdoor air pollution and lung function in children.

- In six year old children, younger than in most previous studies, we investigated the association of lung function with TSP and traffic related pollution. Young children are a susceptible subgroup for air pollution health effects (Kim 2004; Mathieu-Nolf 2002). We targeted six year old children because the adolescent spurt has not started yet (Wang et al 1993 a.; Wang et al 1993 b.). Because of the young age of the subjects, we used measures of lung function which require little collaboration (airway resistance ($R_{aw}$)) and (total lung capacity (TLC)).
- We simultaneously considered the influence of short-term and chronic TSP exposure on lung function. $R_{aw}$ rapidly reacts to short-term exposure by means of bronchoconstriction and/or hypersecretion and might therefore preferentially show acute effects, whereas TLC changes slowly and might show long-term effects.
- We compared effects of TSP exposure on lung function in children from East and West Germany thereby adjusting for many additional changes in life style which occurred between 1991 and 1997 in East Germany after reunification.
- Additionally the effects of traffic related exposure were included in our study. We expected the effects of living near a busy road to increase between 1991 and 1997 in East Germany thereby diminishing the effects of the broad scale decrease in TSP.

## Materials and Methods

### Study subjects and sites

This study is part of a large study in East and West Germany investigating the health effects of the changing environmental and socio-economic conditions after re-unification in school beginners (six years old) between 1991-2000 (Krämer et al. 1999; Krämer et al. 2002). Every school beginner from preselected geographical areas was invited to participate in a questionnaire investigation and every second child was asked to do lung function measurements. Rural areas without heavy industrial impact were Salzwedel and Osterburg in East- and Borken in West Germany, urban areas with industrial impact were Halle-Centre, Leipzig-Southwest and Magdeburg-Centre in East- and Duisburg-North and Duisburg-South in West-Germany. Essen-Centre and Cologne-Centre in West Germany were urban areas with strong traffic burden. Lung function was recorded in East Germany in 1991, 1994 and 1997 and in West Germany in 1991, 1994, 1997 and 2000.

### Study design

Consecutive cross sections of school beginners were investigated to estimate the effect of outdoor pollution with TSP and living near a road with heavy traffic on lung function. Measurements of lung function were airway resistance ($R_{aw}$) and total lung capacity (TLC). Covariates were age, sex, height, body mass index above 18.4 kg/m$^2$ (95$^{th}$ percentile of BMI of study children from East German urban areas in 1991), birth weight below 2400 g (5$^{th}$ percentile of birth weights of study children from East German urban areas in 1991), parental education (highest achieved grade of schooling of either parent; we distinguished 2 grades <=10 (American grade ‘high school’) and >10 years of schooling (American grade ’college and higher degrees’)), bedroom-sharing (one or more person shares the child’s bedroom), single room heating with fossil fuels, cooking with gas, tobacco smoke exposure considering passive smoking at home and/or maternal smoking in pregnancy and temperature below zero degree Celsius at the day of investigation.

## Methods

### Lung function

Lung function was tested with a constant volume bodyplethysmograph apparatus from Jaeger, Würzburg. Principles of this technique were summarized by Ulmer et al. (Ulmer et al. 1991).Testing was done with the same mobile bodyplethysmograph and the same experienced team of examiners in all regions and over all the years of study. The lung function of children suffering from acute airway infection were not recorded as this could confound the results. The investigations were conducted in early spring in East Germany and in late spring in West Germany. Several tests on a child were performed for each respiratory manoeuvre. Registering began with normal respiration for determining $R_{aw}$, followed by maximal expiration and maximal slow inspiration for determining TLC. This method of measurement is precisely described by Coates et al. (Coates et al. 1997). The child's mean values for $R_{aw}$ were used for analysis, however only observations of those children where the measured values of $R_{aw}$ varied less than 0.3 kPa·s/L were included. The chosen value of TLC was the maximum of valid single measurements. Valid measurements of TLC were those where the simultaneously registered inspiratory capacity was within 80 to 140 % of the child's averaged intrathoracic gas volume.

### Exposure

Daily and annual mean values of TSP and $SO_2$ were determined by the regional authorities of Northrhine Westfalia (West German study sites) (Landesamt für Immissionsschutz des Landes Nordrhein-Westfalen 1990), Saxony (Leipzig) (Bezirkshygieneinstitut Leipzig 1990), and Saxony-Anhalt (East German study sites with the exception of Leipzig) (Bezirkshygieneinstitut Magdeburg 1990) by the same method: radiometric technique (β-ray absorption monitor) for determination of TSP; UV-fluorescence method for determination of $SO_2$. Children's exposure to outdoor TSP and $SO_2$ was characterized by the mean of the values gained at the monitoring station(s) (one to three) in the investigation areas. These were either mean values of the year before the study (chronic) or the mean values of the investigation day (short-term). The measurement stations for TSP and $SO_2$ are built to represent urban or rural large scale background exposures. Therefore they are situated far from industrial sources or roads with heavy traffic. These stations may not adequately describe exposure of children who live near roads.

Parents were asked “How far away is your address (beeline) from a busy street (rush hour traffic/ through traffic)” and answer categories were predefined as “less than fifty meter” and “more than fifty meter”. This information was used to define two categories (high and low) of traffic exposure. This assessment was validated in the group of children from West-Germany in 2000 where geo-coded addresses and a road network with traffic density data were available. Daily traffic flow within a circular neighborhood of 50 m radius around a child’s address was calculated as the sum of all products of number of cars per day times the length of its street section for all segments of this network located within the circle. These traffic densities data were compared for children with high and with low traffic exposure as given by questionnaire asessment.

The outdoor temperature was measured during the day of investigation at the place of the mobile bodyplethysmograph and included in the analysis as daily mean temperature.

Questionnaire

Covariates were derived from a questionnaire, which was sent to the parents along with the invitation to the school entrance examination, which is compulsory in Germany. On the day of investigation the questionnaire was checked by physicians from the local Health Authorities and subsequently completed by the parents.

Height and weight of the children were measured using standardized procedures by the assistants of the local Health Authorities.

The ethical committee of the Medical Association of Saxony Anhalt approved the study. Written informed consent was obtained from the parents.

Statistical analyses

Only children with German nationality living more than two years at their residence were included. Furthermore asthmatic children were excluded to evade effects of broncholytic medication.

All analysis were done by linear regression on logarithmically transformed lung function measurements. All covariates mentioned above were included in the regression models. Homogeneity of TSP effects on children from East and West Germany as well as on children living in proximity to and at a distance from busy streets were tested by including product terms . The TSP effects on TLC and $R_{aw}$ were also tested by including a linear term for trend (study year). The estimated parameters of the regression models were expressed as geometric means ratios (MR) of the respective lung function variable for an increment of one unit of continuous variables or for 1 versus 0 of binary variables, adjusted for the remaining covariates. The unit for TSP was 40 µg/m$^3$, that is the span between the 5$^{th}$ and 95$^{th}$ percentile of occurring annual mean values. Possible clustering by area was accounted for by random effect modeling.

All statistical analyses were done with SAS version 8.2 for Windows NT. Regression models were computed with the procedure GENMOD.

## Results

### Response

Lung function data were available for 3540 children (response 69% in West and 73% in East Germany). Children of non-German nationality (n=596), children living less than two years at their place of residence (n=401) and children suffering from asthma (n=64) were excluded from the analysis. This resulted in 2574 valid data for $R_{aw}$ and 2066 valid data for TLC. 3% of the children had no valid measurement for $R_{aw}$, 22 % had no valid measurement of TLC. No lung function differences were found between children with and without valid TLC measurement. Both groups showed identical mean $R_{aw}$ of 0.63 kPa/ls. The lower rate of valid values for TLC compared to $R_{aw}$ is plausible, because TLC measurement requires some motivation for a respiratory maneuver, whereas $R_{aw}$ is virtually independent from collaboration. The final group for analysis consisted of 2275 children where information on all covariates was available.

Exposure

Table 1 shows that TSP and $SO_2$ concentrations in outdoor air decreased mainly in East Germany however a slight decrease was also found in West Germany. When the study started in 1991 the annual mean TSP concentrations in East Germany exceeded West German concentrations by a factor up to 1.5, and the daily mean concentrations were up to three times higher in East than in West Germany. Already in 1994, annual TSP levels were similar in East and West. The annual and daily mean TSP concentrations were moderately correlated (r=0.68). Autocorrelation of TSP concentration values at the day of investigation compared to the day before was r=0.83. Differences in $SO_2$ between East and West Germany and the decrease of $SO_2$ in East Germany were much stronger than for TSP: the annual mean $SO_2$ concentrations in East Germany exceeded West German concentrations by a factor up to five, and the daily mean concentrations were more then ten times higher in East than in West Germany. $SO_2$ and TSP were highly correlated. Annual means showed a correlation coefficient of 0.82 and daily means of 0.82. Since 1997, annual $SO_2$ levels were similar in East and West. The annual and daily mean $SO_2$ concentrations were more strongly correlated (r=0.91) than TSP concentrations. Autocorrelation of $SO_2$ concentration values at the day of investigation compared with the day before was r=0.91.

Parent's judgment about distance to a busy street (table 2) was tested by comparing the two exposure groups with respect to objective measure of traffic density in the sub-sample of children in West Germany 2000, where geo-coded residential addresses and data of traffic density were available. Mean traffic density within 50 m radius around the children's addresses of those claiming high traffic exposure was 216 traveled km/day ( no significant differences between the rural Borken (241 km/day) and the urban Duisburg (204 km/day)) and those claiming low traffic exposure was 34 traveled km per day (26 in Borken and 41 in

Duisburg). The difference between means of traffic exposure groups was highly significant (Wilcoxon test, $p<0.000001$).

Covariates

A description of covariates and traffic exposure is given in table 2. School beginners were slightly younger in East than in West Germany due to the earlier examination phase in East Germany. The prevalence of the adverse lifestyle factors: heating with fossil fuels, gas for cooking and environmental tobacco smoke, respectively, decreased strongly in East and slightly in West Germany since 1991. Low birth weight decreased and body mass index increased in East as well as in West Germany. In West Germany parental educational level seemed to be lower in 2000 than in 1991, maybe due to the selection of different study subareas in the West German study areas. Some East German school beginners in 1991 and 1994 were investigated at temperatures beneath 0ºC, which can elevate the $R_{aw}$ .

Association of TSP and distance to a busy road with lung function

Table 3 shows mean crude lung function parameters grouped by study year and part of Germany. The results of the regression analysis are presented in table 4. The interaction between annual mean TSP and traffic exposure on TLC was significant (MR=1.02 for TSP effect living near a busy road/TSP effect living far from a busy road, $p=0.0004$), indicating that the decrease of TLC per unit TSP was smaller for children living near to a busy road than for those living far away from it. The interaction between daily mean TSP and traffic exposure on $R_{aw}$ was also significant (MR=0.98, $p<0.0001$). The interaction between TSP and region (East/West) on TLC was not significant indicating that the TSP effect on TLC was the same in East and in West Germany. This interaction however was significant for $R_{aw}$.

To facilitate interpretation, the results are also presented stratified by region (East/West) and distance from a busy road in table 5.

In children living further away from a busy road $R_{aw}$ showed a positive association with short-term TSP exposure (mean on the day of investigation) for children from East Germany, but none for children from West Germany. Mutually adjusting of annual TSP with annual $SO_2$

and daily TSP with daily $SO_2$ resulted in loss of significance and paradox direction of short-term TSP effect on $R_{aw}$ in East Germany (data not shown).

TLC was about 3% smaller for children living in residential areas where TSP annual means were increased by 40 µg/m$^3$ when they additionally lived near to a busy street. This result was not significant. However, children dwelling far from busy roads had a TLC reading which was more than 6% smaller when their home was located in a region where TSP annual means were increased by 40 µg/m$^3$. Figure 1 represents this result graphically. As can be seen by comparison of figure 1b with figure 1a, the effect of broad scale TSP on TLC is stronger when only considering children living far from a busy road. The regression coefficients (table 5) were similar in East and West Germany. The effects did not change when not mutually adjusting for short-term TSP. An additional effect of short-term exposure on TLC could not be detected. The chronic TSP effect on TLC scarcely differed when adjusting for annual $SO_2$ (data not shown).

An overall effect of living near a busy road on $R_{aw}$ and TLC could be detected in West Germany. In East Germany, this effect only emerged, when restricting the analysis to children investigated from 1994 onwards (table 6).

Sensitivity analysis

We excluded asthmatics as medication usage could both confound the individual observations and the changing trends over time. On the other hand children with asthma might be more susceptible to air pollution exposures. We therefore repeated the analysis without excluding asthmatic children. As found by Gauderman (Gauderman 2004) effects in total group and group of non-asthmatics did not differ substantially. All effects in the total group however were less pronounced: means ratio for the association between TLC and TSP in East Germany was 0.962 instead of 0.961 and 0.956 instead of 0.953 in West Germany.

Big differences as well as massive changes in indoor combustion sources existed between East and West Germany. In our analyses we adjusted for indoor combustion sources. Additionally we stratified the data by indoor sources and repeated the analysis for the group without special sources. The results did not change and all associations between TSP and lung function stayed significant when excluding children heating their home with fossil fuels, as, for example, the long-term effect on TLC only differed by about one percent with respect to the means ratio.

To account for unknown factors changing over time, we additionally adjusted for trend. The effect estimates for TLC and annual mean TSP in children living more than 50 m from a busy road changed from 0.938 to 0.957, but was still significant. The effect estimate for $R_{aw}$ and daily TSP for East German children living more than 50 m from a busy road changed from 1.025 to 1.027 and remained significant.

There is evidence to suggest that short-term effects of particulate matter may be strongest 2-5 days after the exposure (Delfino et al. 2004). Therefore we considered modeling different lags of TSP exposure and included TSP values from the day before the investigation or the means from the week before the investigation into the analysis instead of the values on the day of investigation. All these measures were highly correlated (TSP on the day of investigation with TSP the day before: r=0.83; TSP on the day of investigation with the of the week before: r=0.82) and the effect estimates did not change; i.e., all relative differences of means ratios between models of different lags were less than one percent.

## Discussion

In 1991, six year old children in East Germany had poorer lung function values than children in West Germany: $R_{aw}$ were higher and TLC lower in East than in West German children. East/West differences in lung function diminished between 1991 and 1997. At the same time the East/West differences in TSP concentrations (daily and annual) also diminished. Lower concentrations of TSP were associated with better measure of lung function in six year old children. TLC was mostly affected by chronic exposure and $R_{aw}$ by short-term exposure. Traffic related exposure had a negative impact on lung function and, for children living near roads with heavy traffic, the positive effect of lower TSP concentrations was smaller.

Although young children might be especially vulnerable to air pollution health effects (Kim 2004; Mathieu-Nolf 2002), data on lung function for this group of children is rarely presented, because lung function measurements using the usual spirometric device is dependent on children's cooperation. We therefore used a mobile bodyplethysmographic device. The TLC measurements, however, require a small amount of cooperation, which might explain the 22% non valid measurements for TLC. We have no indication that the observed TLC results were in any way distorted by the lower number of valid measurements. $R_{aw}$ in children with and without valid measurement of TLC were found to be equal. The overall response rate to our study was reasonable (72%). We assume that our results are not biased by any changes in measuring lung function, because only one team examined the children, the same equipment and same method of measuring, and calculating was used throughout the study period. This restriction to one apparatus had the disadvantage in that the investigations in East Germany could not be done simultaneously to those in West Germany, but always preceded them. As climate and pollen exposure differed between February/March (investigation in East Germany) and April/May (investigation in West Germany), a possible distortion of the East/West German comparison had to be considered. The convergence of mean lung function parameters between 1991 and 1997 is probably not caused by the timing of the studies because in all years the investigations were done in the same months in East and West Germany. Differences in seasonal factors could influence East/West comparisons in lung function over time if they influence lung function and change differently over the investigation years in East and West Germany. Among factors which might have introduced seasonality variation in lung function are (i) temperature, (ii) acute infections and (iii) pollen exposure. (i) Temperature was already adjusted for in the analysis given. No additional effects of temperature above 0°C on lung function could be detected, and the temperature differences between the East and West German investigation time did not change in a systematic way (7.4 °C in 1991, 8.9 °C in 1995 and 4.7 °C in 1997). (ii) Children with acute respiratory infections were excluded from the analysis. (iii) The birch pollen season was always included in the investigation time in West Germany but never in East Germany. There was a trend to earlier birch pollen seasons, however the seasonal mean pollen concentration showed no trend (p=0.3), and we could detect no effect of pollen exposure on lung function in non-asthmatics ($R_{aw}$: MR=0.998, p=0.291, TLC: MR=0.999, p=0.346).The stronger effect of short-term TSP exposure on $R_{aw}$ in East Germany compared to West Germany however could partially be due to the fact that short term TSP concentrations were higher in early spring (investigation in East Germany) than in late spring (investigation in West Germany).

Measurements of $PM_{10}$ (particles with aerodynamic diameter less than 10 μm) or finer particle fractions were not available during the observation period. In Germany low volume samplers were used for measuring TSP. An often used conversion factor ($PM_{10}$/TSP) is 0.86 (Gehrig and Hofer 2000), which seems to be quite constant even during 1991-2000 in East Germany (Heinrich, Munich, personal communication). When using this factor, our result of 3.9% (East combined) and 4.7% (West combined) lower TLC in children exposed to 40 $\mu g/m^3$ higher TSP would transform to 4.6 and 5.4% per 40 $\mu g/m^3$ higher $PM_{10}$.

Other air pollutants like $SO_2$, $NO_2$ or $O_3$ might have caused similar effects as those we ascribed to TSP. $NO_2$ or $O_3$ were only available from 1992 onwards. Short-term $SO_2$ concentration changed from 242 to 10 $\mu g/m^3$ during the observation period and annual means from 127 to 20 $\mu g/m^3$. The TSP effects on TLC remained unchanged whereas the short-term TSP effect on $R_{aw}$ lost significance when adjusting for $SO_2$ additionally. Therefore short-term TSP effects might be due to a combined action of TSP and $SO_2$.

The TSP effect was significant after adjusting for the covariates as presented in table 2. However, there might be the possibility that we missed some covariates which had changed over time. Therefore, in a sensitivity analysis we additionally adjusted for trend. The long-term effects on TLC and the short term effects on $R_{aw}$ were statistically significant even after adjusting for trend. Another aspect which adds to the possible causality of TSP is that the long-term effects on TLC were nearly equally pronounced in East Germany as in West Germany, where lifestyle was different and changes during 1991 to 2000 were much less pronounced than in East Germany.

We found that living next to a busy road had an adverse effect on $R_{aw}$ and TLC. This effect emerged in East Germany only after 1991 indicating strengthening over time. We found that the TSP effects were stronger for children living away from roads with heavy traffic. In this group, $R_{aw}$ was positively associated with short-term TSP concentrations and TLC with long-term concentrations. In East Germany after reunification the number of automobiles increased. In Saxony (East Germany) from 1.2 million to 2.1 million (Statistisches Landesamt des Freistaates Sachsen 2000), in Saxony Anhalt (East Germany) from 0.8 million to 1.2 million (Landesamt für Umweltschutz Sachsen-Anhalt 2004), but in Northrhine Westphalia (West Germany) only from 8 million to 9 million (Ministerium für Verkehr, Energie und Landesplanung des Landes Nordrhein-Westfalen 2004). The number of cars per 1000 inhabitants changed in East Germany from 245 to 488 between the years 1989 and 1997, resulting in a number nearly equal to that found in West Germany (517). Due to propagation of catalytic converters particulate matter (PM) and nitrogen oxide ($NO_x$) emissions from traffic related sources in East Germany did not increase proportionally to the increase in automobile numbers, but peaked in 1993 (PM) and 1995 ($NO_x$) and has since declined in the years thereafter (Landesamt für Umwelt und Geologie, Freistaat Sachsen 1997). The relative contribution of traffic-related sources to all emissions increased between 1989 and 1997 for PM from 2% to 22% and for $NO_x$ from 30% to 48%. A measurement station with traffic exposure in Leipzig, one of our study areas, showed a steady increase of $NO_2$ annual means between 39 $\mu g/m^3$ in 1991 and 53 $\mu g/m^3$ in 1996 (Landesamt für Umwelt und Geologie 1997). The number concentration of ultrafine particles (0.01-0.02µm diameter) in East Germany increased after 1991 despite decreasing TSP concentrations and decreasing concentrations of fine particulate matter ($PM_{2.5}$) (Ebelt et al. 2001; Kreyling et al. 2003). Ultrafine particles from automobile emissions vary on a small spatial scale, they disappear exponentially with the distance from a major road and reach background levels at a distance of 300 m (Zhu et al. 2002). Similar effects can be observed for other traffic related air pollutants. In East Germany, overall background TSP concentrations decreased whereas concentrations of certain traffic-related substances near roads with heavy traffic actually increased. Therefore, it seems plausible that the effects of decreasing TSP concentrations in outdoor air are more pronounced in areas which are further away from roads with heavy traffic whilst the effects are possibly counteracted by the increasing concentrations of traffic-related pollutants. We did not measure traffic-related substances, but relied on questionnaires.

We were able to show in a small validation study that the questionnaire information about a busy road in 50 m distance seems to be a good indicator for traffic in a 50 m radius around the child's address. Lung function of children has been found to be associated with traffic related exposure in a number of other epidemiological studies (Brunekreef et al. 1997; Fritz and Herbarth 2001; Wjst et al. 1993). Nevertheless the counteracting effect of living near a busy road might be caused by factors other than air pollution such as proximity to a busy street would result in less ability to play outdoors because of high volumes of traffic in front of the home.

We are not aware of any other major epidemiological study having measured TLC or $R_{aw}$ in six year old children. Therefore, direct comparisons with results of other groups are difficult. However, forced expiratory vital capacity (FVC) can act as surrogate of TLC because 80% of TLC is respirable and changes of TLC are reflected in changes of FVC in persons without severe respiratory illnesses as emphysema. Therefore qualitative and quantitative comparisons are possible. Peak expiratory flow (PEF) and, to a smaller extent, forced expiratory volume in one second ($FEV_1$) are dependent on resistance and comparisons of effects on $R_{aw}$ with effects on those lung function measures from other studies are possible in a restricted manner.

The association of annual TSP and TLC found in our study shows similarity to the results of the Bitterfeld study in East Germany with repeated cross sections between 1992 and 1999 (Frye et al. 2003). A significant increase of 4.7 % of adjusted FVC, but no effect on $FEV_1$, was reported in schoolchildren aged 11-14 years, when annual TSP decreased about 50 $\mu g/m^3$. Transforming our results to this change of exposure resulted in an increase of 4.9% of TLC. The lack of a long-term TSP-effect on $R_{aw}$ in our study agreed with the lack of an effect for $FEV_1$ in the Bitterfeld study

Furthermore, the TSP associated changes in TLC observed in our study can be compared with changes of FVC in Southern California communities (Peters et al. 1999). The decrease we observed was twice the decrease in Southern California: We observed a 76.7 ml decrease of TLC (corresponding to a 61.3 ml decrease of FVC) associated with a TSP change from 40 to 80$\mu g/m^3$. For the pupils from southern California a 34.3 and 36.9 ml decrease of FVC per increase of 40 $\mu g/m^3$ TSP (calculated from $PM_{10}$) was observed. This comparison is affected by different conditions such as age of children and other copollutants, but exposure of particulate matter was in a similar range of concentration suggesting that our results and the results of the Bitterfeld study might overestimate the effect of TSP. It is likely that trend of air pollution and trend of other factors is not separable during the period of German reunification. However, the regression coefficients for the independent variable TSP with respect to the dependent variable TLC were nearly identical for both parts of Germany. This hints at a causal effect of TSP not confounded by trend.

## Conclusions

This study compares lung function in six year old children in East and West Germany during a time of decreasing concentrations of outdoor TSP in East Germany. The children investigated were of ethnic homogeneity, but differed in lifestyle and air pollution exposure. These differences diminished during the time of observation. No other study is available comparing results from East and West Germany during this critical time of changes. Total lung capacity showed a clear association with long-term concentrations of TSP, resistance was affected by short-term outdoor concentrations in East Germany. Thus, the reduction in TSP was associated with better lung function when comparing repeated cross sections in six year old children. However, there was an increasing effect of traffic related pollution in East Germany, and the favorable effects were presumably counteracted by air pollution associated with the increased traffic.

References

Bezirkshygieneinstitut Leipzig. 1990. Jahresbericht Lufthygiene 1989, Leipzig:Bezirkshygieneinstitut.

Bezirkshygieneinstitut Magdeburg. 1990. Umwelthygienischer Jahresbericht 1989, Magdeburg:Bezirkshygieneinstitut.

Brunekreef B, Janssen NA, Hartog J. 1997. Air pollution from truck traffic and lung function in children living near motorways. Epidemiology 8:298-303.

Coates AL, Peslin R, Rodenstein D, Stocks J. 1997. Measurement of lung volumes by plethysmography. Eur Respir J 10:1415-1427.

Delfino RJ, Quintana PJ, Floro J, Gastanaga VM, Samimi BS, Kleinman MT, et al. 2004. Association of FEV1 in asthmatic children with personal and microenvironmental exposure to airborne particulate matter. Environ Health Perspect 112:932-941.

Dockery DW, Speizer FE, Stram DO, Ware JH, Ferris BG, Spengler JD. 1989. Effects of inhalable particles on respiratory health of children. Am Rev Respir Dis 139:587-594.

Ebelt S, Brauer M, Cyrys J, Tuch T, Kreyling WG, Wichmann H-E. 2001. Air quality in postunification Erfurt, East Germany: associating changes in pollutant concentrations with changes in emissions. Environ Health Perspect 109:325-333.

Fritz GJ, Herbarth O. 2001. Pulmonary function and urban air pollution in preschool children. Int J Environ Health 203:235-244.

Frye C, Hoelscher B, Cyrys J, Wjst M, Wichmann H-E, Heinrich J. 2003. Association of lung function with declining ambient air pollution. Environ Health Perspect 111:1-5.

Gauderman WJ, McConnel R, Gilliland F, London SJ, Thomas DC, Avol E, et al. 2000. Association between air pollution and lung function growth in Southern California children. Am J Respir Crit Care Med 162:1383-1390.

Gauderman WJ, Gilliland GF, Vora H, Avol E, Stram D, McConnel R, et al. 2002. Association between air pollution and lung function growth in southern California children: results from a second cohort. Am J Respir Crit Care Med 166:76-84.

Gauderman WJ, Avol E, Gilliland F, Vora H, Thomas D, Berhane K, et al. 2004. The effect of air pollution on lung development from 10 to 18 years of age. N Engl J Med 351:1057-1067.

Gehrig R, Hofer P. 2000. Vergleichsmessungen von PM10 und totalem Schwebstaub (TSP). Gefahrstoffe-Reinhaltung der Luft 60:389-394.

He QC, Lioy P, Wilson WE, Chapman RS. 1993. Effects of air pollution on children's pulmonary function in urban and suburban areas of Wuhan, People's Republic of China. Arch Environ Health 48:382-391.

Hoek G, Dockery DW, Pope A, Neas L, Roemer W, Brunekreef B. 1998. Association between PM10 and decrements in peak expiratory flow rates in children: reanalysis of data from five panel studies. Eur Respir J 11:1307-1311.

Islam MS, Schlipköter H-W. 1993. Lungenfunktion und Luftverunreinigung. Der Ruhebronchialtonus bei Kindern im Alter zwischen 6 und 9 Jahren in Gebieten mit unterschiedlichen Luftverunreinigungen. Atemw - Lungenkrkh 19:541-546.

Kim JJ. 2004. Ambient air pollution: health hazards to children. Pediatrics 114:1699-1707.

Krämer U, Behrendt H, Dolgner R, Ranft U, Ring J, Willer HJ, et al. 1999. Airway diseases and allergies in East and West German children during the first five years after reunification: time trends and the impact of sulfur dioxide and total suspended particles. Int J Epidem 28:865-873.

Krämer U, Link E, Oppermann H, Ranft U, Schäfer T, Thriene B, et al. 2002. Studying School beginners in western and eastern Germany: allergy trends and sensitisations 1991 - 2000. Das Gesundheitswesen 64 657-663.

Kreyling WG, Tuch T, Peters A, Pitz M, Heinrich J, Stölzel M, et al. 2003. Diverging long-term trends in ambient urban particle mass and number concentrations associated with emission changes caused by the German unification. Athmospheric Environment 37:3841-3848.

Landesamt für Umwelt und Geologie, Freistaat Sachsen, 1997. Jahresberichte zur Immissionssituation 1991-1997.

Landesamt für Umweltschutz Sachsen-Anhalt. 2004. Immissionsschutzbericht 2003.

Landesanstalt für Immissionsschutz des Landes Nordrhein-Westfalen. 1990 Temes-Monatsberichte über die Luftqualität in Nordrhein-Westfalen.

Mathieu-Nolf M. 2002. Poisons in the air: a cause of chronic disease in children. J Toxicol Clin Toxicol 40:483-491.

Ministerium für Verkehr, Energie und Landesplanung des Landes Nordrhein-Westfalen. 2004. Mobilität in NRW, Daten und Fakten 2004.

Peacock JL, Symonds P, Jackson P, Bremner SA, Scarlett JF, Strachan DP, et al. 2003. Acute effects of winter air pollution on respiratory function in schoolchildren in southern England. Occup Environ Med 60:82-89.

Peters JM, Avol E, Gauderman WJ, Linn WS, Navidi W, London SJ, et al. 1999. A study of twelve southern california communities with differing levels and types of air pollution. Am J Respir Crit Care Med 159:768-775.

Pope I, Arden C. 2000. Epidemiology of fine particulate air pollution and human health: biologic mechanisms and who's at risk, Environmental Health Perspectives. Supplements 108:713-723.

Schindl R. 1983. Einfluss der Umweltfaktoren auf die Lungenfunktion. Screeninguntersuchung mit Flow-Volumen bei Schulkindern in Stadt und Land. Z Erkrank Atm-Org 161:199-203.

Schindler C, Künzli N, Bongard JP, Leuenberger P, Karrer W, Rapp R, et al. 2001. Short-term variation in air pollution and in average lung function among never-smokers. Am J Respir Crit Care Med 163:356-361.

Schwartz J. 1989. Lung function and chronic exposure to air pollution: a cross-sectional analysis of NHANES II. 10. Environ Res 50:309-321.

Statistisches Landesamt des Freistaates Sachsen. 2000. Sachsen im Überblick 10 Jahre deutsche Einheit.

Ulmer WT, Reichel G, Nolte D, Islam MS eds. 1991. Die Lungenfunktion. Physiologie und Pathophysiologie, Methodik. Stuttgart:Georg Thieme Verlag.

Wang X, Dockery DW, Wypij D, Fay ME, Ferris BG Jr. 1993a. Pulmonary function between 6 and 18 years of age. Pediatr Pulmonol 15:75-88

Wang X, Dockery DW, Wypij D, Gold DR, Speizer, FE, Ware JH, et al. 1993b. Pulmonary function growth velocity in children 6 to 18 years of age. Am Rev Respir Dis 148:1502-8

Wjst M, Reitmeir P, Dold S. 1993. Road traffic and adverse effects on respiratory health in children. BMJ 307:596-600.

Zhu Y, Hinds WC, Kim S, Sioutas C. 2002. Concentration and size distribution of ultrafine particles near a major highway. J Air Waste Manag Assoc 52:1032-1042.

Table 1: Distribution of TSP[a] and $SO_2$ exposure [μg/m$^3$] from the previous year and from the day of investigation for the children, regression analysis of the logarithmic transformed TSP[a] and $SO_2$ exposure for trend (10 years), region (East vs West) and their interaction (trend East vs Trend West)

| | | West Germany | | | | East Germany | | | MR (95% CI)[a] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1991 | 1994 | 1997 | 2000 | 1991 | 1994 | 1997 | Trend | East/West | Trend East/ Trend West |
| TSP[b] | n | 196 | 282 | 148 | 307 | 903 | 493 | 322 | | | |
| from | Mean | 54.35 | 52.22 | 56.11 | 44.20 | 74.45 | 55.68 | 51.29 | 0.80* | 1.37* | 0.62* |
| the | Std | 2.69 | 3.07 | 2.45 | 4.73 | 5.37 | 3.44 | 10.80 | (0.67,0.96) | (1.24,1.52) | (0.48,0.80) |
| previous | Min | 50.00 | 48.00 | 53.00 | 40.00 | 66.00 | 50.00 | 44.00 | | | |
| year | Max | 56.00 | 55.00 | 59.00 | 50.00 | 81.00 | 59.00 | 73.00 | | | |
| TSP[b] on | n | 196 | 282 | 148 | 287 | 903 | 456 | 322 | | | |
| day | Mean | 51.01 | 53.87 | 45.65 | 49.75 | 127.9 | 68.79 | 49.65 | 0.96 | 2.98* | 0.16* |
| of exam | Std | 21.81 | 17.69 | 15.88 | 20.20 | 35.33 | 37.68 | 29.61 | (0.74,1.23) | (2.39,3.71) | (0.10,0.26) |
| inatio n | Min | 13.00 | 19.60 | 24.60 | 20.00 | 46.00 | 23.40 | 20.00 | | | |
| | Max | 83.00 | 110.3 | 102.9 | 96.00 | 208.0 | 182.2 | 122.0 | | | |
| $SO_2$ | n | 196 | 282 | 148 | 307 | 903 | 493 | 322 | | | |
| from | Mean | 27.25 | 19.73 | 18.27 | 10.07 | 126.9 | 57.65 | 20.19 | 0.33* | 5.06* | 0.17* |
| the | Std | 6.94 | 3.80 | 2.90 | 3-40 | 53.23 | 21.23 | 4.63 | (0.26,0.43) | (3.08,8.30) | (0.10,0.31) |
| previous | Min | 18.00 | 17.00 | 14.00 | 6.00 | 64.00 | 37.00 | 16.00 | | | |
| year | Max | 34.00 | 26.00 | 21.00 | 14.00 | 178.0 | 93.00 | 26.00 | | | |
| $SO_2$ on | n | 196 | 261 | 139 | 301 | 903 | 429 | 322 | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| day | Mean | 19.81 | 13.15 | 12.21 | 8.75 | 241.5 | 79.05 | 10.24 | 0.46* | 20.8* | 0.02* |
| of exam- | Std | 13.61 | 6.42 | 5.88 | 6.15 | 136.9 | 62.73 | 6.01 | (0.33,0.63) | (14.3,30.3) | (0.01,0.03) |
| inatio n | Min | 5.00 | 5.00 | 5.00 | 5.00 | 35.13 | 15.06 | 3.00 | | | |
| | Max | 57.00 | 30.70 | 30.90 | 38.00 | 576.0 | 261.3 | 31.00 | | | |

[a]MR (95% CI): geometric means ratio and 95% confidence interval for trend (10 years), region (East/West), interaction (trend East/trend West), results of linear mixed model analysis, area (exposure from the previous year) or date (exposure from the day of investigation) treated as marginal effect;

[b]TSP: total suspended particles;

*: significant effects ($p<0.05$)

Table 2: Characteristics of the study group

non-asthmatic German children living at least two years at their place of residence

| | West Germany | | | | East Germany | | |
|---|---|---|---|---|---|---|---|
| | 1991 | 1994 | 1997 | 2000 | 1991 | 1994 | 1997 |
| N | 196 | 282 | 148 | 307 | 903 | 498 | 322 |
| age [years], mean | 6.4 | 6.4 | 6.4 | 6.4 | 6.3 | 6.1 | 6.2 |
| height [cm], mean | 120.9 | 121.1 | 120.5 | 120.5 | 119.3 | 119.8 | 120.8 |
| male sex [%] | 50.5 | 47.9 | 43.2 | 46.9 | 52.0 | 50.0 | 57.3 |
| birth-weight <2400 g [%] | 7.2 | 4.3 | 4.1 | 5.6 | 5.2 | 3.9 | 4.1 |
| BMI >18.4 kg/m$^2$ [%] | 7.7 | 8.5 | 10.8 | 12.4 | 6.0 | 7.9 | 9.0 |
| temperature <0 º at day of examination [%] | 0.0 | 0.0 | 0.0 | 0.0 | 41.0 | 15.4 | 0.0 |
| fossil fuel heating at home[%] | 13.1 | 24.3 | 16.4 | 6.8 | 69.4 | 44.5 | 26.1 |
| gas cooking at home [%] | 8.3 | 8.9 | 4.8 | 3.9 | 73.0 | 56.7 | 33.5 |
| parental education school yrs <=10 [%] | 53.9 | 50.2 | 67.6 | 70.8 | 49.1 | 55.6 | 49.2 |
| bedroom sharing [%] | 58.8 | 53.0 | 41.5 | 52.8 | 64.8 | 57.5 | 42.7 |
| tobacco smoke exposure[a] [%] | 59.3 | 55.6 | 50.7 | 35.9 | 52.9 | 49.5 | 37.6 |
| traffic exposure[b] [%] | 45.9 | 63.1 | 59.5 | 46.4 | 63.0 | 69.8 | 56.9 |

[a]tobacco smoke exposure: smoking of mother during pregnancy and/or smoking at child's home;

[b]traffic exposure: living in a distance <50m to a traffic road

Table 3: Lung function of German Children not suffering from asthma and living at least two years at their place of residence

| | West Germany | | | | East Germany | | |
|---|---|---|---|---|---|---|---|
| | 1991 | 1994 | 1997 | 2000 | 1991 | 1994 | 1997 |
| airway resistance $R_{aw}$ [kPa.s/L] | | | | | | | |
| N | 188 | 275 | 148 | 307 | 883 | 451 | 322 |
| Min | 0.247 | 0.261 | 0.427 | 0.352 | 0.255 | 0.309 | 0.300 |
| 25$^{th}$perc[a] | 0.467 | 0.519 | 0.594 | 0.546 | 0.553 | 0.553 | 0.562 |
| median | 0.554 | 0.594 | 0.673 | 0.626 | 0.651 | 0.634 | 0.641 |
| 75$^{th}$perc[a] | 0.678 | 0.715 | 0.763 | 0.704 | 0.773 | 0.725 | 0.749 |
| Max | 1.008 | 1.465 | 1.352 | 1.015 | 1.710 | 1.286 | 1.267 |
| AM[b] | 0.579 | 0.620 | 0.698 | 0.634 | 0.672 | 0.650 | 0.665 |
| total lung capacity TLC [L] | | | | | | | |
| N | 156 | 188 | 137 | 257 | 664 | 373 | 291 |
| Min | 1.49 | 1.31 | 1.50 | 1.41 | 1.22 | 1.35 | 1.39 |
| 25$^{th}$perc[a] | 1.96 | 2.01 | 1.99 | 2.02 | 1.85 | 1.94 | 2.00 |
| median | 2.13 | 2.16 | 2.11 | 2.18 | 2.06 | 2.13 | 2.19 |
| 75$^{th}$perc[a] | 2.35 | 2.39 | 2.30 | 2.38 | 2.24 | 2.36 | 2.39 |
| Max | 2.71 | 3.33 | 2.92 | 3.08 | 3.34 | 2.97 | 3.50 |
| AM[b] | 2.14 | 2.21 | 2.15 | 2.20 | 2.05 | 2.15 | 2.20 |

[a] perc: percentile; [b]AM: arithmetic mean

Table 4: Influence of long-term and short-term TSP[a] concentrations on lung function of German non-asthmatic children living at least 2 yrs at their residence, analysis non-stratified, but with interaction terms

| | N | MR (95% CI)[b] | | | | | |
|---|---|---|---|---|---|---|---|
| airway resistance [kPa.s/L] | | TSP[a] annual mean | TSP[a] daily mean | interaction TSP[a] daily mean*traffic | interaction TSP[a] daily mean*region | traffic | region |
| | 2216 | 0.994 (0.957,1.033) | 0.969* (0.936,1.004) | 0.973* (0.965,0.981) | 1.053* (1.012,1.097) | 1.072* (1.056,1.089) | 0.984 (0.925,1.046) |

| | N | MR (95% CI)[b] | | | | | |
|---|---|---|---|---|---|---|---|
| total lung capacity [L] | | TSP[a] annual mean | TSP[a] daily mean | interaction TSP[a] annual mean*traffic | interaction TSP[a] annual mean*region- | traffic | region |
| | 1763 | 0.938* (0.884,0.996) | 0.996 (0.988,1.004) | 1.020* (1.006,1.034) | 1.012 (0.951,1.076) | 0.973* (0.955,0.991) | 0.996 (0.909,1.092) |

[a]TSP: total suspended matter;

[b]MR (95% CI): adjusted geometric means ratio and 95% confidence interval for 40 µg/m$^3$ increase of TSP, traffic (living less than versus equal or more than 50 m from a busy road), region (East versus West German sites) and their interactions with TSP. Results of linear mixed model analysis; adjusted for education, bedroom sharing, sex, age, height, body mass index, birth weight, heating with fossil fuels, cooking with gas, passive smoking and/or maternal smoking during pregnancy, temperature on the day of investigation; area treated as marginal effect;

*: significant effects (p<0.1);

Table 5: Influence of long-term and short-term TSP[a] concentrations on lung function of German non-asthmatic children living at least 2 yrs at their residence, stratified analysis

| | West | | | East | | |
|---|---|---|---|---|---|---|
| | N | MR (95% CI)[b] | | N | MR (95% CI)[b] | |
| | | TSP[a] annual mean | TSP[a] daily mean | | TSP[a] annual mean | TSP[a] daily mean |
| airway resistance [kPa.s/L] | | | | | | |
| traffic | 416 | 1.111 (0.922,1.338) | 0.942* (0.918,0.967) | 927 | 0.984 (0.945,1.014) | 0.996 (0.976,1.016) |
| non traffic | 343 | 1.096 (0.966,1.243) | 0.982 (0.938,1.028) | 530 | 0.967 (0.901,1.038) | 1.025* (0.999,1.051) |
| total lung capacity [L] | | | | | | |
| traffic | 328 | 0.973 (0.913,1.038) | 0.981* (0.971,0.992) | 724 | 0.969 (0.930,1.009) | 0.998 (0.993,1.003) |
| non traffic | 278 | 0.930* (0.875,0.988) | 1.007 (0.976,1.040) | 433 | 0.938* (0.910,0.967) | 0.999 (0.985,1.012) |

[a]TSP: total suspended matter;

[b]MR (95% CI): adjusted geometric mean ratio and 95% confidence interval for 40 µg/m$^3$ increase of TSP. Results of linear mixed model analysis; adjusted for education, bedroom sharing, sex, age, height, body mass index, birth weight, heating with fossil fuels, cooking with gas, passive smoking and/or maternal smoking during pregnancy, temperature on the day of investigation; area treated as marginal effect.

*: significant effects (p<0.1)

Table 6: Influence of living near a busy road on lung function of German non-asthmatic children living at least 2 yrs at their residence

| | | West | | East | | East 1994/1997 |
|---|---|---|---|---|---|---|
| | N | MR (95% CI)[a] | N | MR (95% CI)[a] | N | MR (95% CI)[a] |
| $R_{aw}$[b] [kPa.s/L] | 770 | 1.019* (1.003,1.035) | 1488 | 1.007 (0.989,1.025) | 363 | 1.021* (1.005,1.037) |
| TLC[c] [L] | 617 | 0.994* (0.991,0.998) | 1182 | 1.006 (0.998,1.014) | 306 | 0.989* (0.986,0.992) |

[a]MR (95% CI) adjusted geometric means ratio and 95% confidence interval for living less versus equal or more than 50 m away from a busy road. Results of linear mixed model analysis; adjusted for education, bedroom sharing, sex, age, height, body mass index, birth weight, heating with fossil fuels, cooking with gas, passive smoking and/or maternal smoking during pregnancy, temperature on the day of investigation; area treated as marginal effect;

[b]$R_{aw}$ airway resistance;

[c]TLC total lung capacity;

*: significant effects (p<0.1)

Figure Legends:

Figure 1

Total lung capacity of German children living more than 50 m (a) and equal or less than 50 m (b) away from a street with heavy traffic, living at least two years at their place of residence and not suffering from asthma Place and year specific geometric mean values and regression line adjusted for education, bedroom sharing, sex, age, height, body mass index, birth weight, heating with fossil fuels, cooking with gas, passive smoking and/or maternal smoking during pregnancy and temperature on the day of investigation

Symbols refer to place and year of investigation:

Key to symbols:

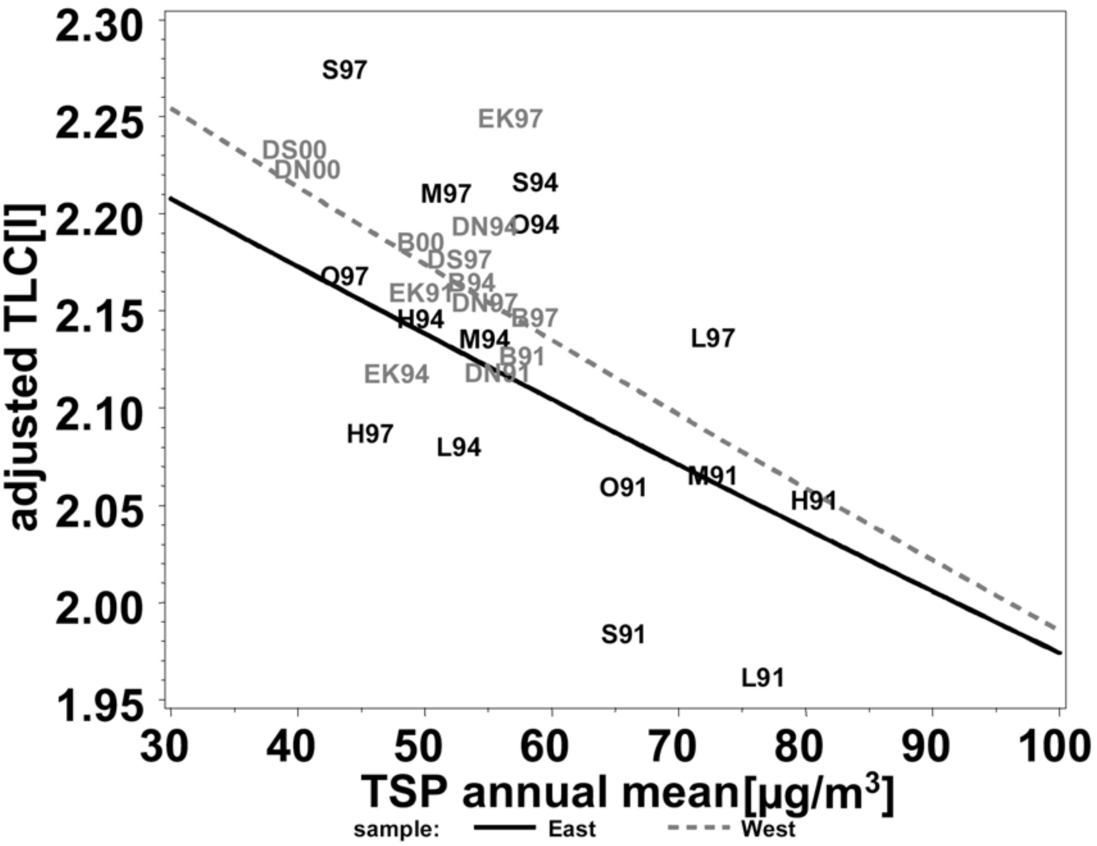
L: Leipzig, H: Halle, M: Magdeburg, O: Osterburg, S: Salzwedel,

DS: Duisburg South, DN: Duisburg North, EK: Essen and Cologne, B: Borken

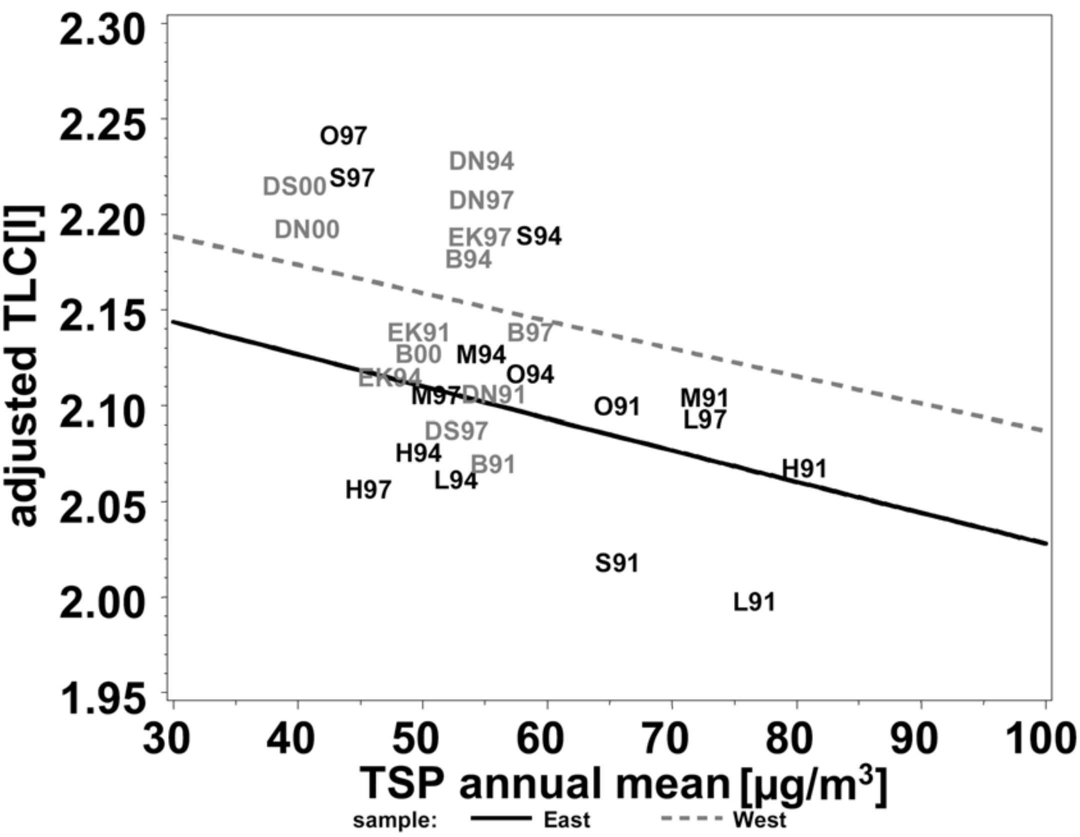
91: 1991, 94: 1994, 97: 1997, 00: 2000

Figure 1

(a)


2.30
2.25
2.20
2.15
2.10
2.05
2.00
1.95
adjusted TLC[l]
30
40
50
60
70
80
90
100
TSP annual mean[µg/m3]
sample: East West
S97
EK97
DS00
DN00
M97
S94
DN94
O94
B00
DS97
O97
B94
EK91
DN97
H94
B97
M94
L97
B91
EK94
DN91
H97
L94
M91
O91
H91
S91
L91

(b)


2.30
2.25
2.20
2.15
2.10
2.05
2.00
1.95
adjusted TLC[l]
30
40
50
60
70
80
90
100
TSP annual mean [µg/m3]
sample: East West
O97
DN94
DS00
S97
DN97
DN00
EK97
S94
B94
EK91
B97
B00
M94
O94
EK94
M97
DN91
O91
M91
L97
DS97
H94
B91
H91
H97
L94
S91
L91